Revisiting Historical Meteotsunami Events in Lake Huron
Eric J. Anderson¹, Chin Wu², Adam Bechle³, Philip Chu¹, Shanxiang Wu²
¹NOAA/OAR/GLERL, ²University of Wisconsin-Madison, ³Wisconsin Sea Grant

Background
Meteotsunamis are a global phenomena that risk property damage, loss of life, and impacts on navigation (Candelone et al., 1999; Iwasa et al., 2007; Vilibic et al., 2008; Dragani et al., 2009; Sejic et al., 2009; Thompson et al., 2009; Arano et al., 2012; Paquet and Vilibic, 2013; Vilibic et al., 2014). Meteotsunamis are long waves with periods between 2 minutes to 2 hours that are generated by an atmospheric disturbance, similar to a convective storm, which most commonly entails a sharp gradient in pressure and rise in wind stress (Bechle and Wu, 2014; Sejic and Rabinovich, 2014). In the Great Lakes, or other enclosed basins, unique dangers exist due to the reflection and interraction of meteotsunami waves. Often meteotsunamis can appear long after the inducing storm has passed, increasing the danger posed to coastal communities.

Meteotsunami Occurrence
Recent work by Bechle et al., (2016) has shown that meteotsunamis occur in each of the Great Lakes, resulting in death and destruction to coastal communities (Fig. 1), with the largest number of detected meteotsunami recorded in southern Lake Michigan and along the southern shore of Lake Erie. The largest meteotsunami recorded occurred near Chicago, IL in 1954 (Bechle and Wu, 2014). Results suggest that the majority of meteotsunamis in the Great Lakes are driven by complex and linear connection, though the peak occurrence varies by lake, likely due to variability in the resonant characteristics of each lake and the relationships between atmospheric conditions and water depth.

Lake Huron
- Lake Huron experiences more than 10 events each year (Bechle et al., 2016)
- First event recorded on May 23, 1925 (Ludington Sunday Morning News)
- May 5, 1952: 2-foot event caused damage in Mackinaw City and Harbor Beach (Donn, 1959)
- August 22, 1971: 1-foot event (Murty & Freeman, 1973)
- July 13, 1995: Two derechos result in meteotsunamis that cause 4.6-feet water level change (Sejic & Rabinovich, 2014)
- May 31, 1998: a meteotsunami event lead a boat overturned and one drowning in Georgian Bay (NOAA Storm Prediction Center, 2004)
- September 23, 2017: a renovated meteotsunami was detected, though minor in impact, the wealth of high-frequency observations and improved atmospheric and hydrodynamic models available during this event enable a detailed investigation into the mechanisms behind meteotsunami formation in Lake Huron

Data and Methods
- Water level data is available from NOAA/CO-OPS and Fisheries and Oceans Canada (Fig. 2)
- 1995: 1-hour intervals data for US gauges and 15-min intervals data for Canadian gauges
- 2017: 6-min intervals data for US gauges and 3-min intervals data for Canadian gauges
- Meteorological data is available from NOAA and ARSR (Fig. 3)
- 1995: 1-hour intervals data at 2 NDBC buoys (n=2) and 1 or 2 hours intervals data at 5 surface away stations (n=3)
- 2017: 1-min intervals data at 5 surface weather observation stations and 6-min intervals data at 8 meteorological observation stations (n=6)
- Semi-implicit Cross-scale Hydrodynamic Integrated System Model (SCHISM/SELFIE)
- Seamless simulation of 3D baroclinic circulation across a creek-lake-estuary-shelf-ocean scales
- Finite-element/finite-volume method with Eulerian/Lagrangian
- Unstructured mesh with mesh size from 100m to 1500m
- Simulate 1995 and 2017 events with reconstructed meteorological forcing

Conclusions
- Meteotsunamis occur in all Great Lakes, connected to rip current incidents
- Lake Huron experiences >10 events per year
- Historic meteotsunamis reveal largest impacts in southern Lake Huron
- Huron is most sensitive to storms propagating at 24-26 m/s from the SE or E
- Great Lakes meteotsunamis driven by complex and linear convective storms
- High-res models capture the mechanisms behind meteotsunami formation

May 5, 1952
An atmospheric disturbance crossed Lake Huron and Lake Erie with a propagation speed of 16.1 m/s, pressure jump of 4.06 mbar (Fig. 4) and increased wind speeds. Resonant coupling to grainless and edge waves induced large fluctuations in water level. At Harbor Beach, water levels surged 2.2 feet with a period of 63 minutes, and continued for several hours. Similar effects were observed in Lake Erie and at other gauges in Lake Huron (Donn, 1954).

July 13, 1995
Between July 13th and 15th, four derechos crossed the upper midwest, two of which had significant impacts on Lake Huron (Fig. 4). The first event had a propagation speed of 24.1 m/s, which matches the long wave speed in Lake Huron, thus inducing Proudmant Resonance. Wind speeds reached 12 m/s, with a pressure change of 340 Pa (3.4 mbar). Water level observations as a result of the meteotsunami were detected at several gauges (Fig. 4), with greatest magnitudes felt in the southern part of the lake, and with a maximum recorded fluctuation of 4.6 ft (1.4 m) at Lakeside. As a result of the storm, dozens of boats were capsized or destroyed on rocks along the shoreline, and one boater was killed as a result. The US Coast Guard received 152 calls for assistance. Using observed winds and pressure records, a reconstructed meteorology was applied to the Lake Huron hydrodynamic model (Fig. 4), following the methods used in Anderson et al., (2012). Results show even a simplified moving disturbance is able to partially resolve the meteotsunami event, including the maximum water level fluctuation in the southern region of the lake. However, limitations in the idealized atmospheric forcing causes the model to underpredict the water withdrawal after the initial surge, as well as fluctuations along Canadian gauges.

September 23, 2017
A convective storm crossed Lake Huron on Sept. 23, 2017, traveling southeast with a propagation speed of 16 m/s. The wind speed associated with the storm reached 9 m/s, accompanied by a pressure change of 1.9 mbar (190 Pa). Although not sufficient to induce Proudmant Resonance, edge waves were produced that traveled southward along the shoreline. High-frequency water level oscillations were detected at several US and Canadian gauges (Fig. 4), with the largest fluctuation detected at Lakeside in the southern region of the lake.